Goals & configuration of an induced CO_2 leakage experiment at Teapot Dome, WY

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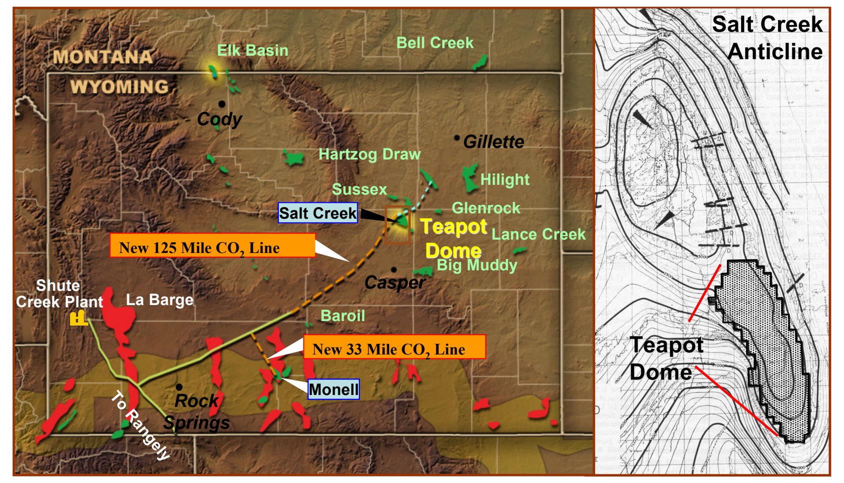
Abstract

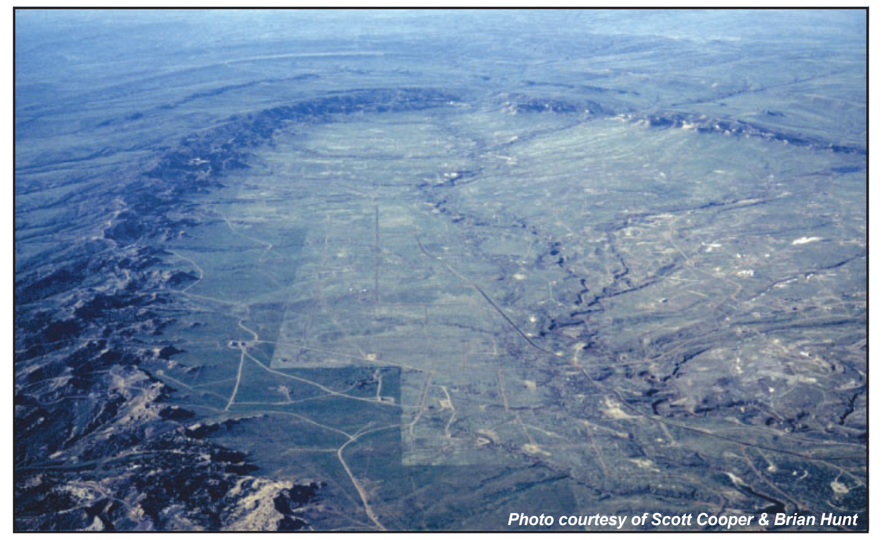
Plans have begun to study the conditions of CO2 leakage along a fault zone from a geological reservoir by direct experimentation. This will take place at the Teapot Dome experimental facility at the Rocky Mountain Oilfield Testing Center/NPR-3. The target fault zone crops out at the surface of the oil field, and can be seen where it cuts the Parkman Sandstone and across the field's width. 3D seismic mapping has delineated the character & geometry of the fault at depth with high resolution. At the surface, calcite veins within the fault zone contain samples of "dead" hydrocarbons, evidence of previous leakage. Alkali springs occur within the zone, and soil sample surveys present evidence of local very high methane concentrations. Thus, the potential for induced leakage is quite high. Geochemical fingerprinting approaches will relate the surface hydrocarbons to specific reservoirs at depth.

The fault zone offsets three potential injection targets: The Shannon Sandstone (~500'), the 1st Wall Creek (~1700'), and the 2nd Wall Creek (~2100') each oil-bearing. Before injection, well and seismic data will be used to understand the near-fault reservoir characteristics and to build geochemical & geomechanical models to predict leakage. Many wells penetrate all three units near the fault that can house subsurface arrays of monitoring tools and techniques. We anticipate using triaxial microseismic monitoring, electrical resistance tomography (ERT), vertical seismic profiling (VSP) and cross-well seismic methods, noble gas tracing, and soil surveys as the minimal monitoring suite. We anticipate adding more tools and techniques during the planning process.

Teapot Dome: Test Bed for Carbon Storage Science



A new pipeline for Anadarko's Salt Creek project has made possible the Teapot Dome field experimental facility. Teapot Dome (NPR3), run by the Rocky Mtn. Oilfield Testing Center (RMOTC) for the DOE, provides a stable research platform to develop and test carbon storage technology and to conduct scientific investigations. These results can be immediately applied to local carbon storage (EOR, Saline Aquifer) in Wyoming & the Rockies (e.g., Mahoney Dome or Grieve). Many results can be applied to commercial storage worldwide (e.g., Appalachians, California, North Sea, China, India)



- 1300 wells
- 600 active wells
- 3D seismic
- 100 years production data
- All public domain

- 9 oil-bearing units
- 6 water-bearing units
- Clastics & carbonates

Teapot Dome differs from many demonstration projects (e.g., Sleipner, Weyburn) in that is primary goal is scientific and technical discovery. Results from research are and will be public domain. As part of its mission, Teapot will serve the needs of the DOE's Regional Carbon Sequestration Partnerships. We anticipate the participation of collaborators from academic, industrial, and government sectors in the US and abroad.

Research and Injection Targets

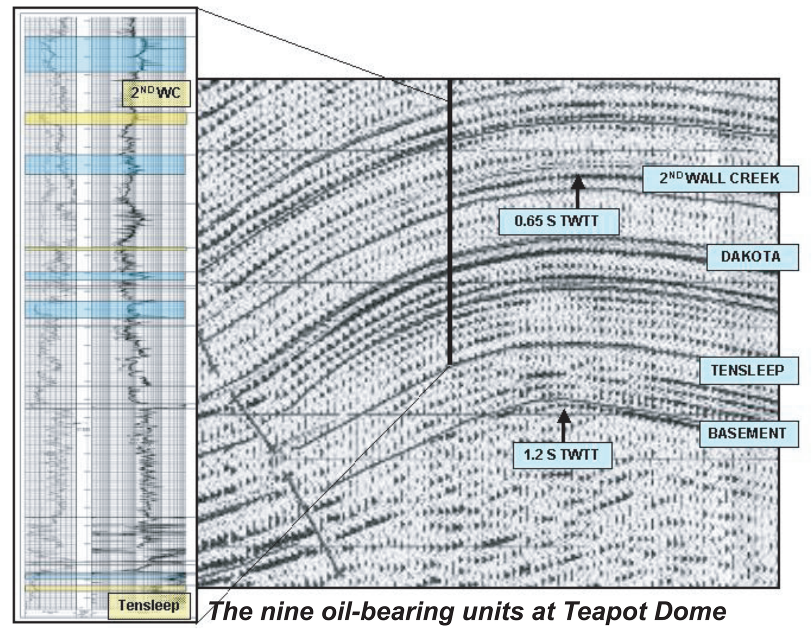
Three critical questions drive the current research effort in geological carbon storage.

Capacity Estimation

Leakage Risk Characterization

CO_2 Storage Monitoring

The research effort at Teapot Dome focuses on these three issues. The initial two experiments aim to maximize CO_2 storage in a depleted oil field and to predict and initiate leakage from a shallow target. Both experiments will use multiple monitoring approaches to measure success and provide scientific insights.



The nine oil-bearing units at Teapot Dome

MAXIMIZE STORAGE

The target reservoir, the Tensleep, and its equivalents hold 2/3 of Wyoming's hydrocarbons -- an excellent first target.
- -- Eolian ss (ϕ ~10%, κ =1-100 (30) mD)
- -- Sabkha evaporite, carbonate, shale cap
- -- 27 wells in small area (manageable)
- -- 5500 ft (~1670 m) depth
- -- Core, log, & production data

LEAKAGE TARGET

The 2nd Wall Creek reservoir, the Frontier equivalent, is the main producer in this structural trend, including Salt Creek
- -- Fluvial-Deltaic ss (ϕ ~12%, κ = 10-200 mD)
- -- Marine shale cap
- -- Many wells near leakage target area
- -- 2000 ft depth (~600 m) depth
- -- Core, log, & production data

The Induced Leakage Experiment

Public, industrial, and regulatory concerns regarding geological carbon sequestration center on health, safety, and environmental risks associated with CO_2 leakage, either slow or catastrophic. However, there has not yet been an effort to study leakage in a controlled setting. A major goal of the work at Teapot Dome is to engineer and induce a CO_2 leak for the purpose of scientific study. This will ultimately help to build a concensus on the general safety of carbon storage, as well as construct a legal and regulatory framework underlain by scientific knowledge.

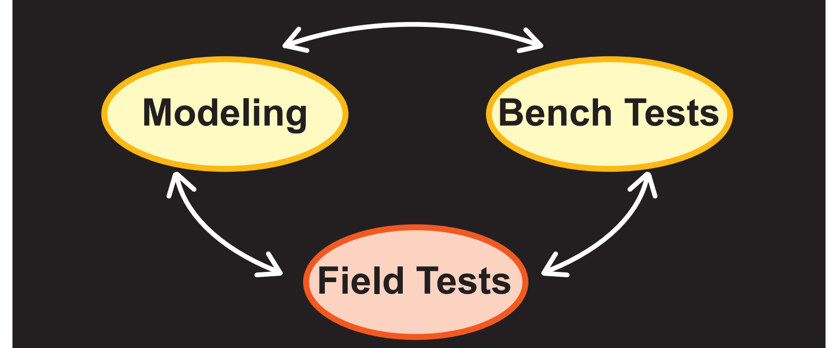
We hope to begin injection in 2006 after completing baseline characterization & mapping (in progress). This will lead to site selection, instrumentation, and modeling before injection.

The experiment will proceed in five phases:

1) Predict the location, pressure, rates, and preferred pathway for failure & leakage
2) Induce failure through injection
3) Measure and monitor leakage successfully
4) Match & cross-compare the prediction to the field case
5) Attempt to mitigate leakage through a variety of technique.

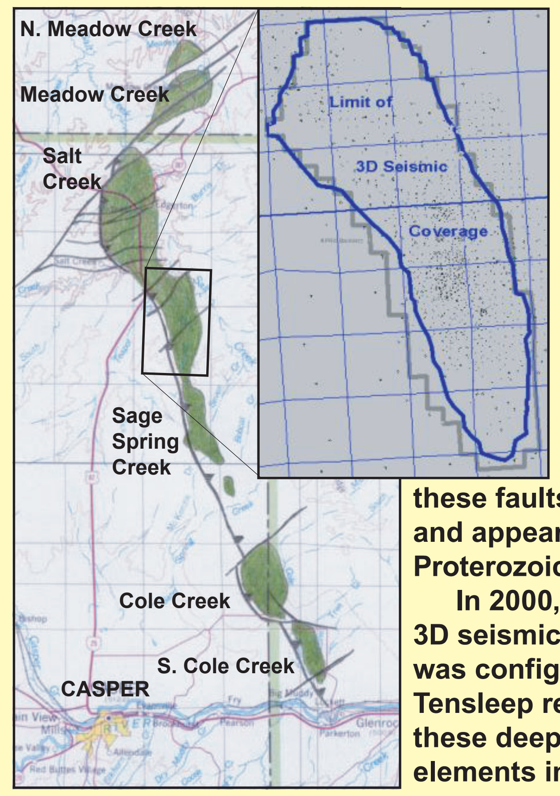
If the experiment succeeds, we hope to follow up with additional experiments in locations less likely to leak, so as to better understand the range of potential setttings for leakage.

The Critical Work Flow



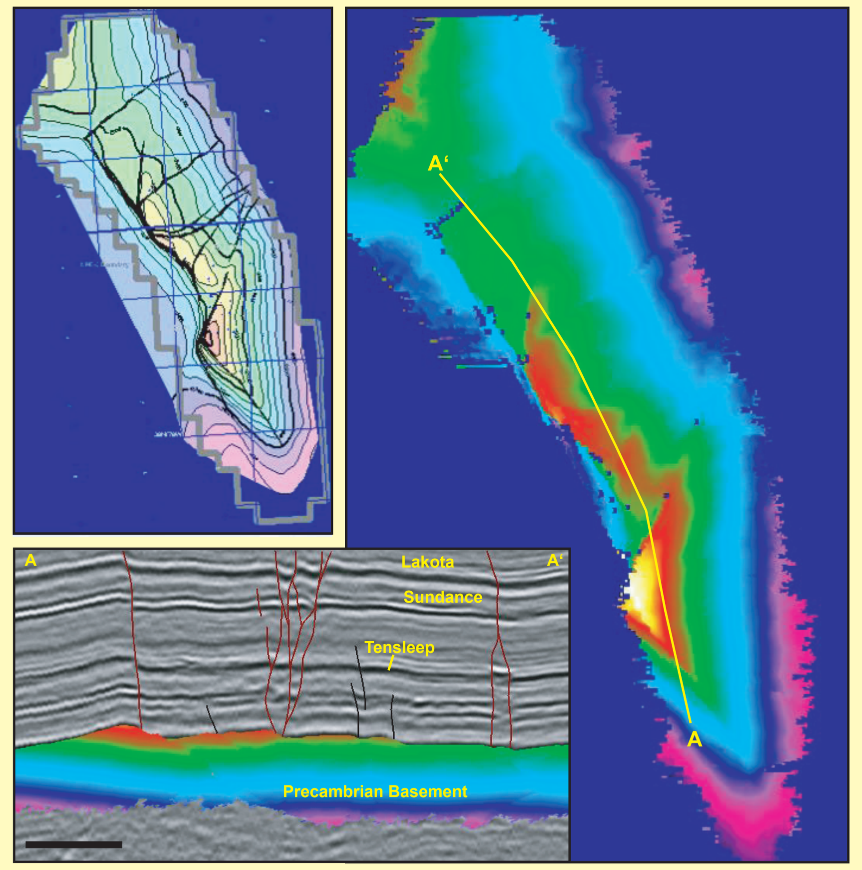
The induced leakage experiment will include aspects of all three approaches, although there is an emphasis on the field effort. Modeling includes reactive transport models, geomechanical models, & monitoring tool forward models. Benchtop work will include experimental geochemistry, rheology, & capillary entry pressure characterization.

Structural Setting

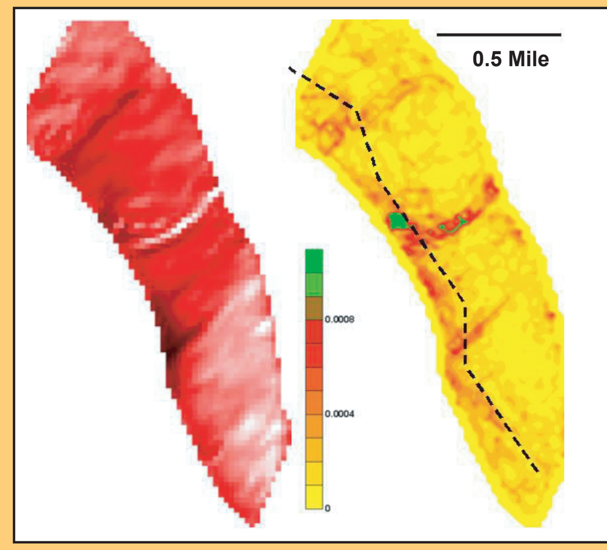


Teapot Dome is one in a series of fault-bounded, asymmetric, Laramide-style, fault-cored anticlines of the Salt Creek trend. The basement blocks verge southwest, and contain a set of SW-NE trending high-angle faults that act as accommodation structures. Many of these faults root into basement and appear to reactivate older Proterozoic lineaments.

In 2000, RMOTC collected a 3D seismic survey. This survey was configured to image the Tensleep reservoir and reveals these deeper structural elements in detail.

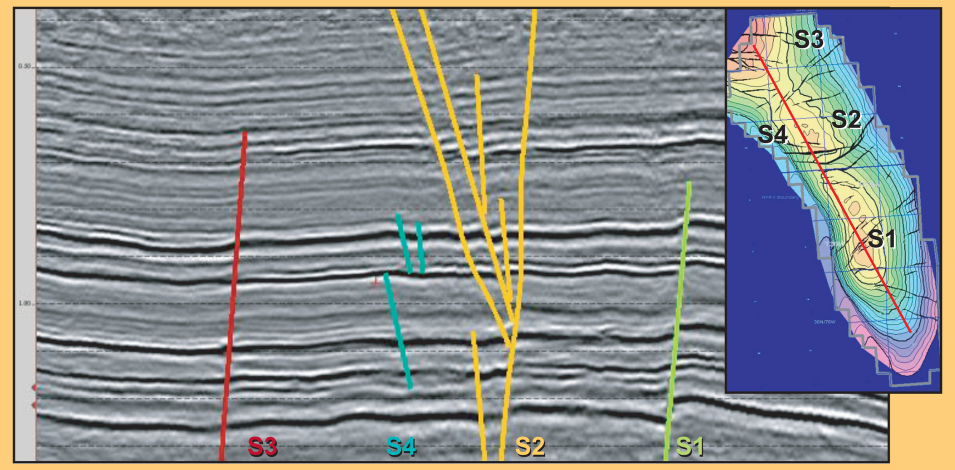


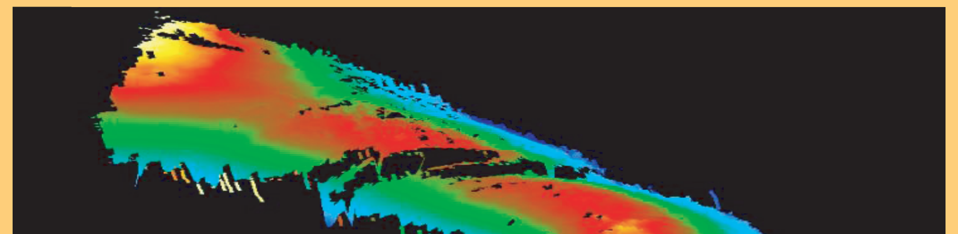
Tear Fault Networks



Accommodation fault networks occur throughout the section, and are easily seen in cross-sections, amplitude maps (L), or discontinuity maps (R). These maps of the Red Peak (between 2nd Wall Creek and Tensleep) are typical. They are also well expressed at the surface.

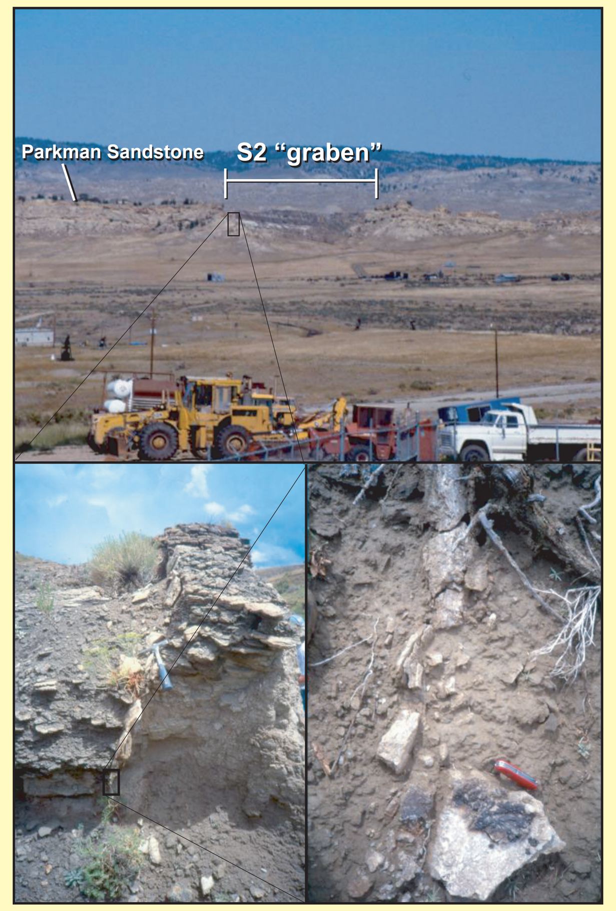
Accommodation fault networks within the section reveal different offsets and timing. Some (e.g. S3) decrease in offset upwards and show clear evidence of syn-depositional faulting. Others (e.g., S2) show increased offset upwards. The geometries range from relatively simple to complex and show different senses of slip along the fault length. We interpret these as oblique-slip faults.



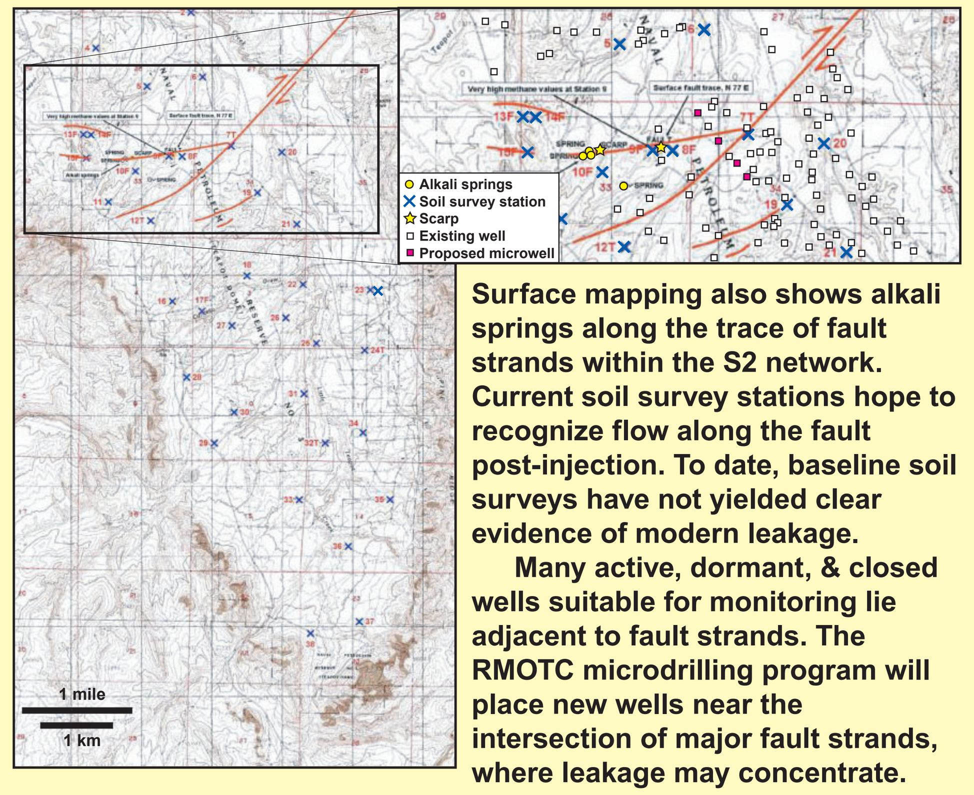


Individual strands of a given network are high delta-throw faults. For all of these reasons, it is highly likely that the fault geometric complexity will increase the risk of fault leakage during injection due to local pressure and stress changes.

S2 Fault Network



The S2 fault network shows the greatest range of orientations, offsets, delta throws, individual strands, and overall geometric complexity. This suggests a higher risk of leakage overall, and several lines of geological evidence confirm leakage from depth along the S2 network. Fault surfaces and gouges are cemented with carbonates; some of these contain dead oil within the veins, indicating prior hydrocarbon leakage. We are currently working with the USGS to determine the source of the dead oil at depth via organic geochemistry.

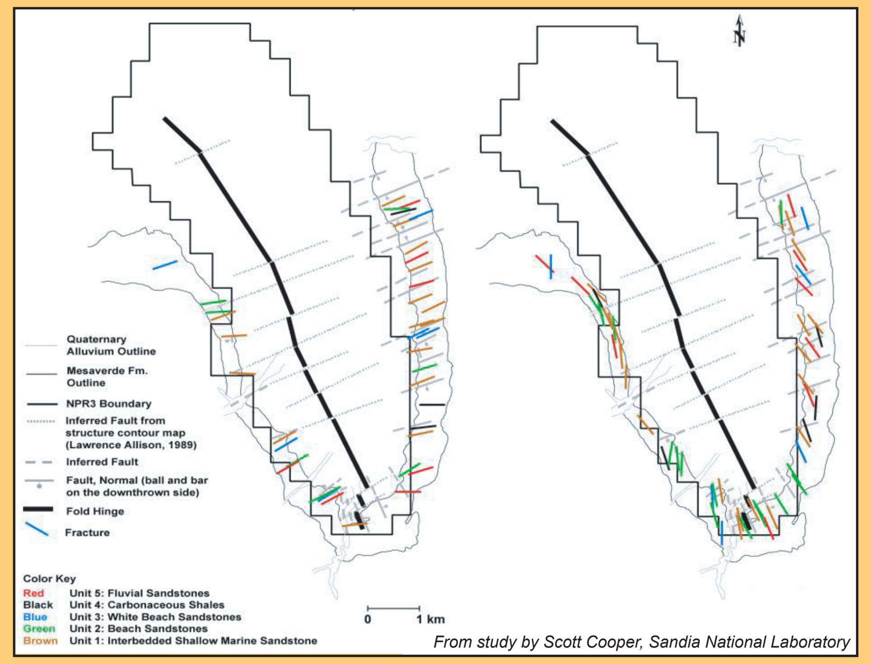


Surface mapping also shows alkali springs along the trace of fault strands within the S2 network. Current soil survey stations hope to recognize flow along the fault post-injection. To date, baseline soil surveys have not yielded clear evidence of modern leakage.

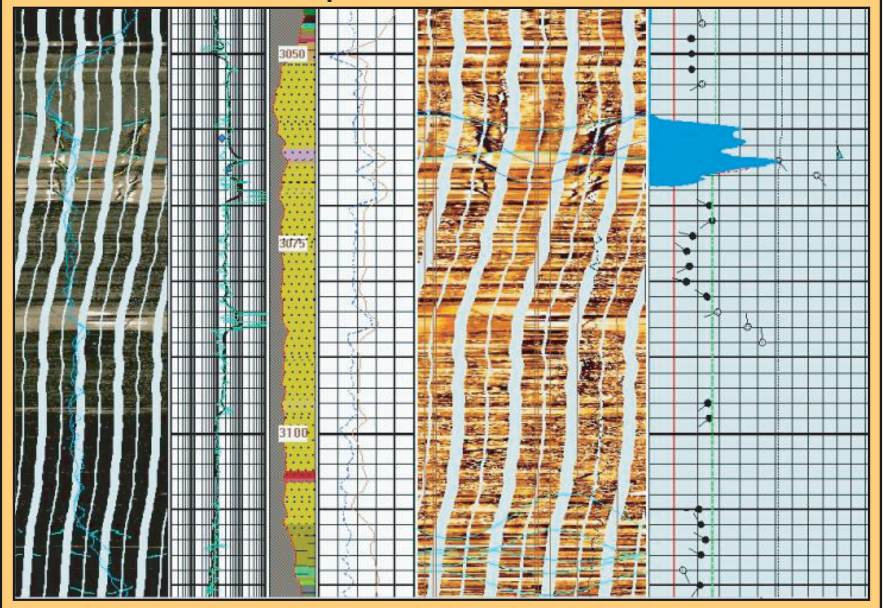
Many active, dormant, & closed wells suitable for monitoring lie adjacent to fault strands. The RMOTC microdrilling program will place new wells near the intersection of major fault strands, where leakage may concentrate.

Fracture Networks

Fractures represent much of the porosity and permeability in the Teapot Dome reservoirs. Several surface and subsurface studies at Teapot Dome have characterized these fracture systems, and drilling in pursuit of enhanced fracture permeability has proven succesful. We believe that fractures in the reservoir and cap rock increase the risks associated with leakage, improving the chance of experimental success.

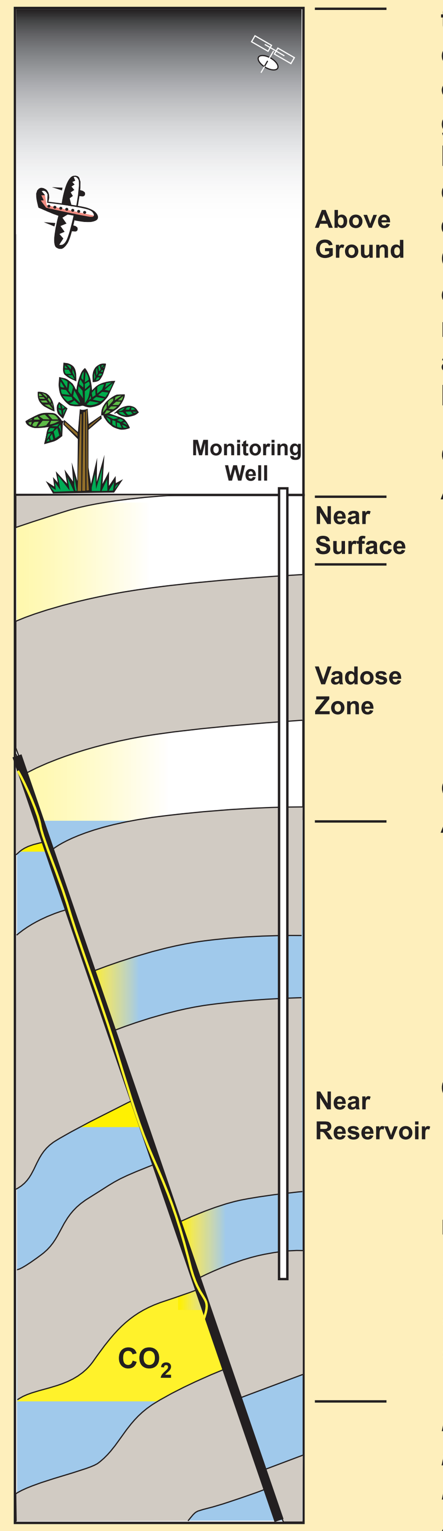


Sub-vertical fractures appear in large part as orthogonal sets, both perpendicular and parallel to vergence and the accommodation faults. Injection of CO_2 into the reservoir should cause dilation in one fracture set or both. Current efforts to characterize the in-situ stress tensor remain vital to accurate fracture flow prediction.



Measurement, Monitoring, & Verification (MMV) Technology

Scientific gains, long term success, and evolving regulatory and economic rubrics depend on effective MMV capabilities. Large projects will require MMV in these four key spatial domains. A wide range of geophysical & geochemical tools will be needed for these different environments. Cross-calibration and comparison of cost, resolution, & precision are goals of the leakage project.



Geophysical Approaches
- 4D seismic
- Cross-well seismic
- VSP
- ERT and EMIT
- Microseismic
- Tilt-meters
- microgravity

Geochemical Approaches
- Brine sampling
- Well-head sampling
- Tracers (noble gas)
- Tracers (isotopes)
- Tracers (CFC's)
- Pre-leakage

Other Approaches
- Airbourne imaging
- Space-based
- Surface nanodetectors

WE ANTICIPATE USING THE MAJORITY OF THESE TECHNIQUES TO MONITOR THE INDUCED LEAKAGE EXPERIMENT. WE ALSO HOPE TO TEST NOVEL METHODS

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